ECONOMIC EVALUATION OF SECTORAL EMISSION REDUCTION OBJECTIVES FOR CLIMATE CHANGE: BOTTOM-UP ANALYSIS OF EMISSION REDUCTION POTENTIALS AND COSTS FOR GREENHOUSE GASES IN THE EU

EXECUTIVE SUMMARY

This report summarises the results of a two year long study using the so-called "bottom-up" methodology. The goal of this study is to identify a least-cost allocation of objectives for different sectors and greenhouse gases so that the European Union would meet its Kyoto target of –8% in 2008-2012 compared with 1990. In a parallel report the results using a "top-down" methodology is presented.[1] The results of both studies are combined and compared in the main report of the study.[2].

The "bottom-up" methodology is the engineering-economic analysis of individual emission reduction options. This approach consists of the following steps:

- For each sector (or sub-sector) the various processes that cause greenhouse gas emissions are identified.
- For the relevant processes an inventory is carried out of the technical emission reduction options that are available.
- The options that can make a contribution to emission reduction in the year 2010 are characterised on the following aspects: emission reduction potential; investment costs; operation and maintenance costs; operational benefits (e.g. energy cost savings); lifetime.

The information on the individual options can be used to calculate total emission reduction potentials and associated mitigation costs by sector, by country and by gas. The information is collected in a database called GENESIS. The bottom-up analysis comprises all greenhouse gases that are subject to the Kyoto Protocol, namely carbon dioxide (CO_2), and the non-CO_2 greenhouse gases methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). Furthermore the analysis covers all economic sectors with an identified emission reduction potential. The classification of economic sectors is based on the Nomenclature des Activités de la Communauté Européenne (NACE).

To determine the potential and costs of greenhouse gas emission reduction options in the EU15 in 2010, the following steps are taken:

1. Collection of base year emission data (1990/1995);
2. Preparation of a 2010 frozen technology reference level of emissions, i.e. no change in emission level per unit of production compared to 1990;
3. Identification, definition and characterisation of technical emission reduction options.

In the bottom-up the frozen technology reference level (FTRL) is prepared for the calculation of the emission reduction potential that could be realised during 2008-2012. The FTRL is a reference level in which no additional development to reduce emissions from 1990 onwards are included. The use of a FTRL provides the

[1] P. Capros, N. Kouvaritakis, L. Mantzos (2001): Top-down Analysis of Greenhouse Gas Emission Reduction Possibilities in the EU, National Technical University of Athens, Athens, March 2001.

[2] K. Blok, D.de Jager and C. Hendriks: Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change – Summary Report for Policy Makers, ECOFYS, AEA Technology, NTUA, Utrecht, March 2001.

opportunity to show the efforts that have been made in realising emission reductions from 1990 on. Using this bottom-up methodology it is possible to identify the technical reduction potential on a sectoral basis and to include those options where it is uncertain whether they will be implemented autonomously. Emissions shown in the frozen technology reference level are not a forecast of 2010 emissions but constructed for analytical purposes only.

The database GENESIS contains technology and cost information on over 250 reduction options (56 for the energy supply sector, 24 for fuel related emissions, 91 for industry, 17 for transport, 32 for households and services, 18 for agriculture and 13 for the waste sector). It should be noted that even this level of detail does not cover the full variety of options that are available. The potential and cost will often depend on local conditions that can not be covered in a general database. However, differences between the Member States are taken into account, if relevant. For instance, differences in climate makes building insulation more effective in reducing emissions in Finland than in Spain. Doing so, the study gives a reliable approximation of the emission reduction potentials and associated costs on the sector, Member State and on the European Union sector level.

The information is used to generate an overview of emission reduction options, taking into account the following.

- The total potential of emission reduction compared to the FTRL is given.
- For the calculation of the specific mitigation it is necessary to choose a discount rate. In our calculation a social discount rate is used. As a standard value 4% is taken.

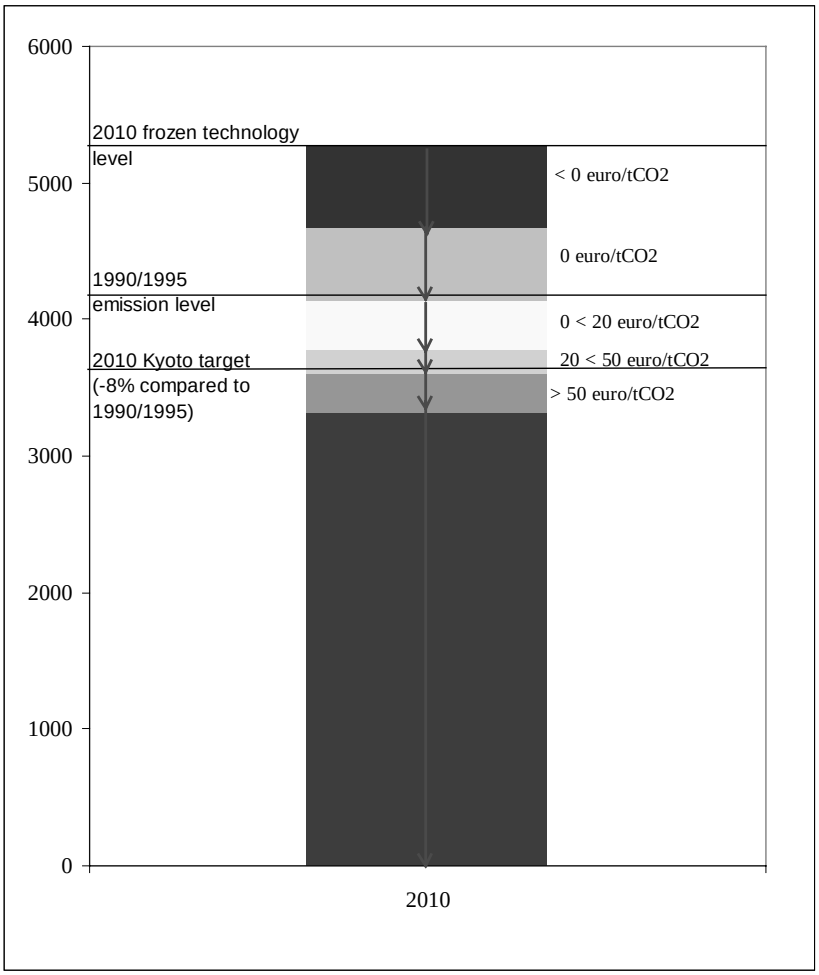
Overall Results

The total of emission reduction options identified equals 1953 Mt of CO_2 equivalents compared to the frozen technology reference level. This results in an attainable emission level of 3332 Mt, which is about 20% below the 1990/1995 emission level. The emission reduction by cost category is given in Figure 1.

The figure shows that many options can be taken at net negative costs, i.e. the monetary benefits of an option are larger than the costs. Most of these options are energy efficiency improvement options in the end-use sectors. The category of zero cost options mainly is made up of fuel switch in the electricity sector[3].

[3] The costs of fuel switch in the electricity sector, e.g. the switch from coal to natural gas, is highly sensitive to local market situations and highly uncertain due to the ongoing liberalisation and privatisation developments in the energy sector. The net costs may be slightly positive or slightly negative. For that reason they are set to zero.

Figure 1 How emissions can be brought down by 2010 from the frozen technology reference level, i.e. the level at which no reduction options are implemented at all since 1990. Arrows indicate the emission reductions in various cost categories. For comparison, the 1990/1995 level and the 2010 target level are indicated.



Options with negative or zero costs represent about 64% of the identified reduction potential.

Measures in the low-cost category (smaller than about 20 $euro_{1990}/tCO_2$ equivalents) comprise of emission reduction of nitrous oxide in the chemical industry (nitric acid and adipic acid), renewable energy sources (some biomass applications, wind energy (onshore), hydropower), improvements at vehicles (both passenger and freight transport) and insulation of existing dwellings and numerous energy efficiency improvement options in all energy demand sectors. This category represents about 14% of the reduction potential.

Most important measures in the medium cost category (20 - 50 $euro_{1990}/tCO_2$ equivalents) comprise of insulation of services buildings, emission reduction of methane through waste incineration and replacement of the grey cast-iron natural gas distribution network, chemical vapour deposition in the semiconductor industry (emission reduction of PFCs) and various measures for HFCs in all sectors (e.g. cooling, air conditioning, foams). This group represents about 7% of the reduction potential.

The remaining 15% comprises about 60 options in all sectors. The most important reduction option in this category is CO_2 removal and storage, with an assumed reduction potential of 50 Mt CO_2 in 2010. This figure may actually vary from 10 to 100 Mt CO_2, depending on the acceptance of this option and the success of demonstration projects for various emission sources and storage concepts. The storage capacity in the European Union is estimated at about 950 $GtCO_2$, which is equal to storage of all 1990 CO_2 emissions over a more than 200 year period.

Results by sector

The energy industries sector

The energy industries sector includes the production of electricity and steam as well as refineries. The energy industries sector is one of the important emitters of carbon dioxide. In addition a relative small amount of nitrous oxide and methane is emitted. Next to this, gas-insulated switch gears are a source of SF_6.

By far the most important emission limitation option in this sector is fuel switch - mainly from less efficient coal-fired plant to high efficient natural gas-fired plants - in the electricity production sector. Compared to a situation in which the fuel mix and efficiency level would remain the same as in the mid-nineties, the switch makes a difference of 500 Mt of CO_2.

Combined heat and power generation can also contribute significantly to greenhouse gas emission reduction. If combined heat and power generation is applied instead of combined cycle power plants, carbon dioxide emissions are reduced by 64 Mt.[4] Costs of carbon dioxide emission mitigation are in the range between 10 and 150 $euro_{1990}$ per tonne of CO_2 (and higher if the plants have to be built in a situation of excess capacity).

One more important option is the application of renewable energy sources. The total emission reduction potential of these sources is 230 Mt[5] of CO_2. Biomass energy is most important, followed by wind energy and hydropower. Some biomass options occur with negative net costs; a substantial part (onshore wind and hydropower) has low costs but also options with costs of 100 $euro_{1990}$ per tonne and higher are available.

Finally, carbon dioxide removal (recovery from an electricity production process and subsequent subterranean storage) can be applied at costs of about 50 $euro_{1990}$ per tonne of CO_2 avoided. It is uncertain to what extent the option can be harnessed until the year 2010, but a provisional estimate is 50 Mt of CO_2.

Options outside the power and steam sector are energy efficiency improvement options in refineries (23 Mt of CO_2 equivalent) partly at zero or net negative costs (e.g. application of improved catalysts in refineries). However, reduction potential and

[4] If combined generation of heat and power is applied directly replacing the average fuel mix, the effect is bigger, i.e. 350 Mt of CO_2, and consequently the costs per tonne of CO_2 are smaller.

[5] If renewable energy is applied directly replacing the average fuel mix instead of natural gas-fired combined-cycle power plants, the effect is bigger, i.e. emission reduction is about 315 to 335 Mt of CO_2.

costs are hard to determine as these options concern a limited number of refineries with big mutual differences.

Fossil fuel extraction, transport and distribution
Methane emissions related to fossil fuel extraction, transport and distribution occur at coal mining, the oil and natural gas upstream activities and the natural gas transport and distribution.

In the reference level, these methane emissions are expected to decrease from 95 to 60 Mt of CO_2 equivalent, mainly due to the expected decrease in coal production in the EU.

In total, a reduction potential of 34 Mt of CO_2 equivalent is identified.
- Methane emission reduction from coal mining (9 Mt of CO_2 equivalent) at near zero costs.
- Methane emission reduction from natural gas system generally cheap from winning and transport (5 Mt of CO_2 equivalent); but more expensive in case of distribution (20 Mt of CO_2 equivalent).

Industry sector
The manufacturing industry consists of a variety of sectors. From the point-of-view of greenhouse gas emissions, a number of energy-intensive sectors, including iron and steel production, the chemical industry and the cement industry are most important. Apart from energy-related CO_2 some process related emissions are relevant: e.g. carbon dioxide from cement production; nitrous oxide from adipic acid and nitric acid production; and PFCs from aluminium production.

A range of technologies that can improve energy efficiency is most important for further reducing these emissions. Some important options are improved pressing and heat recovery in pulp and paper production; vapour recompression; debottlenecking in the petrochemical industry; and the application of thin slab casting techniques in the iron and steel production. The total potential for reduction is 533 Mt of CO_2 compared to the frozen technology reference level.[6]. Of the total amount of emission reduction potential 468 Mt has zero or negative costs.

Important emission reduction options for non-CO_2 greenhouse gases are:
- N_2O emission reduction in the remaining adipic acid plants and in nitric acid production. 66 Mt of CO_2 equivalent, of which already 62 Mt has been implemented before 2000.
- Emission reduction of HFC-23 in HCFC-22 production (7 Mt of CO_2);
- PFC emission reduction in the aluminium industry (5 Mt of CO_2) and in the semiconductor industry (14 Mt of CO_2).

Important policy consequences are:
- Industrial energy efficiency is an important source of low-cost emission reductions; target setting for industrial energy efficiency is hard to attain on the level of individual options but can be better set at the level of sub-sectors.

[6] This includes emission reductions achieved in the energy sector through more energy efficient production of electricity and steam.

- Emission standards can be set for a limited number of industrial sources of non-CO_2 greenhouse gases where relatively cheap emission reductions can be attained.
- Further research is required to determine how adaptations in material production and consumption systems can contribute to the reduction of greenhouse gas emissions.

Transport sector

Passenger cars and freight vehicles account for over three-quarters of emissions. Another main source of emissions is domestic and international aviation.[7] Minor sources of emission are rail, and inland and maritime navigation. Besides emission originating from combustion of fuel, transportation also contributes to emissions of industrial fluorinated greenhouse gases associated with mobile air conditioning and nitrous oxide from the use of catalytic converters.

The sector study on transport considers options for reducing greenhouse gas emissions from the two main sources of transport related emissions: passenger cars and freight vehicles. Three types of options are identified: operational, strategic and demand related options. The latter two generally rely on influencing behaviour. Due to data unavailability and the influence of localised parameters on effectiveness estimates of costs and impacts across the EU could not be made.

Total emission reduction is estimated at about 116 Mt of CO_2 equivalent in 2010 from the frozen technology reference level. 62% of this amount can be reduced from passenger cars, the remaining 27% from freight transport, and about 11% from reducing emissions from air conditioning systems. The reduction from passenger cars is effectively the amount that is expected to be reduced due to the agreements with ACEA, JAMA and KAMA.

Household sector

The sector households is an important source of greenhouse gas emissions, both directly through combustion of fossil fuels for heating purposes and indirectly through its electricity consumption. There is also a small contribution to the emission of fluorinated gases.

Options to be taken in households have in total a potential of 190 Mt of CO_2 emission reduction compared to the frozen technology level. Nearly half of it can be realised at low or net negative costs. These options include improved insulation of existing dwellings, improved practices in new building construction, and improved efficiency of lighting and household equipment. Also important, but more expensive options are the application of better insulating windows, condensing boilers, heat pumps and solar domestic hot water systems.

[7] Emissions from international aviation should not be taken into account both in the reported emissions and in the emission reduction potential. However, due to the fact that no data exist yet on the split between domestic and international air transport emissions, the split has not been made.

Services sector
In the services sector energy is mainly used for space heating, space conditioning and lighting, causing both direct and indirect carbon dioxide emissions. Next to this, some contribution is expected in the future from HFC emissions. The building stock is expected to grow strongly.

For the services sector an emission reduction potential of 126 Mt of CO_2 equivalent is identified, of which about two-thirds shows net negative costs. A very important option is the improvement of energy management in buildings. Also retrofitting of buildings with insulation is relevant for low-cost emission reduction. More efficient lighting systems and office equipment are smaller options.

An important, but more expensive (35 $euro_{1990}$ per tonne of CO_2) option is the application of better insulating windows. Some options for non-CO_2 emission reduction have comparable costs, but are much smaller in size.

Agriculture
In agricultural practices, emission of methane from enteric fermentation in ruminants, nitrous oxide from soil processes and both gases from animal manure are most important. A decrease in emissions is expected partly related to the Common Agricultural Policy reforms.

Emission reduction options in the agricultural sector minimise enteric methane emissions from ruminants by improving feed conversion efficiency, by increasing animal productivity and by improving rumen efficiency through the use of feed additives. Options to reduce emissions from manure are changing feed intake and digestibility and improved manure management systems. For reducing emissions from soil various options are identified, but for most of them the potential, applicability and costs could not be well identified. Mainly, because the main 'driving force' for implementing these options is not to reduce greenhouse gas emissions.

Emission reductions for methane and nitrous oxide are possible through:
- increased animal productivity for ruminants;
- improving feed conversion efficiency for ruminants;
- application of feed additives for ruminants;
- changing manure management practices (e.g. anaerobic manure digestion).

The overall reduction potential is limited to 21 Mt or 4% of the baseline for methane and nitrous oxide, of which about two-third shows net negative costs.

Emission reduction options for CO_2 were not specifically analysed in this study.

The waste sector
The main source of emission from waste is methane from landfills. In landfill anaerobic methanogenic bacteria break down biodegradable carbon compounds and produce methane. In the frozen technology reference level emissions are about 2% higher in 2010 compared to 1990 level. However, emission from landfills are expected to go down due to the recent approval of the Landfill Directive requiring the amount of biodegradable waste going to landfill to be reduced, and methane emissions to be captured.

Emission reduction options are directed towards an alternative way to treat biodegradable waste, e.g. by composting, bio-mechanical pre-treatment, incineration and recycling of paper and cardboard. Alternatively, landfill gas can be collected and combusted or oxidation of the landfill gas in the landfill gap can be improved, thus avoiding the methane escaping to the atmosphere.

The overall emission reduction to the FTRL is estimated at 67 Mt of CO_2 equivalent About 32 Mt will be obtained by currently implemented policies. About 35 Mt of CO_2 could be obtained by planned activities.

Conclusion

The Kyoto target of 8% reduction in the 2008-2012 period compared to the 1990/1995 base year emission level relates to the emission sources as presented in Table A, i.e. the reduction target is 1480 Mt of CO_2 (from the 5284 Mt of CO_2 equivalent in the frozen technology reference level). Compared to the baseline emissions (based on the Primes baseline[8] reference level this means a reduction of 330 Mt of CO_2 equivalent).

The results of this study show that the Kyoto target can be realised by a set of options with specific costs up to almost 20 $euro_{1990}/tCO_2$. The sectoral breakdown of this reduction potential is presented in Table A. The table shows the emission reduction that can be obtained by options in the end-use sectors and by options in the energy supply sector.

Table A. Sectoral contribution to an emission reduction of over 8% in the first budget period compared to base year emissions. All options with specific costs lower than 20 $euro_{1990}/tCO_2$ equivalent are taken into account.

Emission breakdown per sector Mt CO_2-eq.	*Emissions in 1990 or 1995*	*Emissions in 2010 FTRL*	*Emissions in 2010 FTRL (including progress until 1998/2000)*	*Emissions in 2010 under Kyoto target conditions*	*Change from 1990 or 1995*	*Change from 2010 FTRL*	*Change from 2010 FTRL (including progress 1998/2000)*
Direct emisisons							
Energy supply - CO_2 fuel related [1/2/]	1268	1960	1551	1298	2%	-34%	-16%
Direct and indirect emisisons							
Energy supply - other emissions	58	45	42	42	-1%	1%	0%
Fossil fuel emissions[3/]	95	61	43	51	-46%	-16%	18%
Industry[2/]	1463	1984	1623	1113	-24%	-44%	-31%
Transport [4/]	776	1134	1114	1069	38%	-6%	-4%
Households	749	843	759	567	-24%	-33%	-25%
Services	413	653	560	434	5%	-34%	-23%
Agriculture	417	396	407	382	-8%	-4%	-6%
Waste	166	169	124	144	-14%	-15%	16%
Total	**4138**	**5284**	**4672**	**3801**	**-8%**	**-28%**	**-19%**

Breakdown per gas Mt CO_2-eq.	*Emissions in 1990 or 1995*	*Emissions in 2010 FTRL*	*Emissions in 2010 FTRL (including progress until 1998/2000)*	*Emissions in 2010 under Kyoto target conditions*	*Change from 1990 or 1995*	*Change from 2010 FTRL*	*Change from 2010 FTRL (including progress 1998/2000)*
Carbon dioxide - fuel related	3068	4194	3690	2893	-6%	-31%	-22%
Carbon dioxide - other	164	183	169	182	11%	-1%	8%
Methane	462	412	343	370	-20%	-10%	8%
Nitrous oxide	376	379	354	282	-25%	-26%	-20%
HFCs	52	84	84	53	1%	-38%	-38%
PFCs	10	25	25	19	87%	-27%	-27%
SF6	5	7	7	3	-41%	-53%	-53%
Total	4138	5285	4672	3801	-8%	-28%	-19%

[8] P. Capros, N. Kouvaritakis, L. Mantzos (2001): Top-down Analysis of Greenhouse Gas Emission Reduction Possibilities in the EU, National Technical University of Athens, Athens, March 2001.

Options in the energy supply sector have a contribution of 661 Mt of CO_2 equivalent. Reduction options for non-CO_2 greenhouse gases in the end-use sectors contribute 181 Mt of CO_2 equivalent, of which industry 123 Mt of CO_2 equivalent. A substantial part of this potential (62 Mt of CO_2 equivalent) is already realised by the implementation of the reduction options in the adipic acid manufacture industry.

Implementation of the most cost-effective package of options to reach the Kyoto target will reduce emissions of carbon dioxide by 5%; emission of non-CO_2 greenhouse gases will be reduced by 20%.

Also an attempt is made to show the emission reduction obtained in the period 1990 to 2000. In the table (see column "Emissions in 2010 FTRL (including progress until 1998/2000))" it can be seen that the FTRL level in 2010 would be lowered by 612 Mt of CO_2 equivalent if the year 1998 (for process-related CO_2 non-CO_2) and 2000 (for fuel-related CO_2) would have been the base year. It should be noted that these numbers are indicative only.

Reference :

Chris Hendriks, David de Jager, Kornelis Blok et al.. 2001. 'Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change: **Bottom-up Analysis** of Emission Reduction Potentials and Costs for Greenhouse Gases in the EU', ECOFYS Energy and Environment / AEA Technology, Utrecht, The Netherlands, March 2001.

http://europa.eu.int/comm/environment/enveco/climate_change/sectoral_objectives.htm